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EXTRUSION CASTING OF STEEL IN SOVIET ZONE GERMANY

The customary method employed at present to turn molten steel into a form which can be rolled or forged is pouring it into cast-iron ingot molds. The molten steel solidifies in the molds, while the well-known solidification phenomena take place, which lead to the formation of segregation zones and pipes. The solidified ingots are stripped from the mold, go through a preliminary rolling process in a blooming mill train, or are forged to size in forging presses or hammers. If heavy plates are to be made, they are rolled directly from ingot slabs cast in rectangular molds, without the use of a blooming mill train. A similar process is used for tubes, some of which can be made from ingots. In the case of rimmed steel, the pipe formation does not matter very greatly, because the ingots will become compact inside at welding temperature, and the original pipe will not have any harmful effect. Only the overlapping parts at the ends, which are formed during the rolling, have to be cut off. The yield, if both this loss and the loss due to scaling in the soaking furnace are considered, amounts to approximately 90%.

In the case of killed steels with a higher carbon content, or alloyed steels, the situation is different. In these types of steel, the pipe does not shrink, and the ingot end with the pipe must be cut off. This will cause a loss of about 20%, depending on the quality of the steel. By using the proper ingot molds which have an inverted conical shape, the pipe can be localized in the top, and the danger of the formation of a secondary pipe, which would occur otherwise, can be avoided in this manner. These inverted conical molds are to be given preference for alloyed steels. Our experiments with all kinds of charges have shown that the most favorable ratio between the length of the ingot without the cap and its mean diameter is 3:1, with a taper of 7 to 8%. This shape has also proved to be practical for forging ingots. It must be borne in mind that this process necessitates extensive casting pit operations, for which space, pouring gates, runner stones, cranes, and manpower are continuously needed, in addition to which soaking ovens and rolling mills to reduce the cross section of the ingot are required. (To give an idea of the cost, it should be pointed out that a blooming installation alone costs 8 to 10 million marks). Furthermore, there is a loss of material, due to the necessity of removing the ingot ends, so that the costs of the semifinished product are increased.

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It is therefore natural that attempts have been made for the past 50 years to solve the problem of direct casting into semifinished products (extrusion casting). The difficulties involved in the extrusion casting of steel are mainly working with such large quantities, and perhaps an inadequate knowledge of the individual thermal processes which take place. It must also be taken into account that metallurgists are afraid to experiment, especially since the extensive electrification and mechanization of the existing plants have cut the overhead considerably. It is therefore not surprising that extrusion casting first gained a foothold in the light metals industry, which has only recently become highly developed. I know of two extrusion casting processes in the light metals industry, used in Germany. The first is the VLW process (developed by the Vereinigte Leichtmetallwerke Hannover), the second is the Junghans process of the Schorndorf plant near Stuttgart.

In the VLW process, the metal is poured into a furnace which keeps it at constant temperature. From this furnace the metal flows through a water-cooled ring of a height of 100 mm onto a plate which moves in a vertical direction. The diameter of the ring has the desired cross section. The ring is fastened in a vessel to the upper edge of a water vat. The bottom of the vessel touches the water level of the vat. When casting is begun, a plate attached to a bar is pushed up to the underside of the ring and closes it, so that the metal can fill only the free volume of the ring. As soon as the metal starts solidifying along the edges, the plate is slowly lowered. The metal thus is surrounded by water and continues to solidify. At the same time, new metal continues to pour into the ring and the process goes on until the plate rests on the bottom of the vat. At that point, the process is interrupted, and the ingot is pulled out. Then the entire operation is repeated.

In the Junghans process, the metal is poured into a water-cooled copper ingot mold which is about 300 mm high. This mold can be moved vertically, in order to reduce a relative effect (Relativ-Wirkung) along the walls of the mold to a minimum. This is carried out by slowly moving the mold downward for about 20 to 30 mm, and then rapidly moving it upward again. When the pouring starts, the mold is closed from the bottom by a metal plate fastened to a vertical wooden bar. The plate is lowered gradually, after the outside of the ingot has started to solidify. A few meters directly underneath the mold, there is a pair of rollers whose rotation is coordinated precisely with the rate of flow of the metal into the mold. As soon as the lower end of the solidified metal has gone between the rollers, the process goes on continuously. Underneath the rollers, the rods or slabs are cut to the required length by metal saws or cutting torches and are carried off on a horizontal roller conveyer. The pouring rate in this process is a function of the cooling rate in the ingot mold.

Both processes have been used to cast thousands of tons of nonferrous metals, and have become indispensable to the industry. The great success of the extrusion casting method in the light metals industry has aroused the interest of the steel industry, and the Junghans method has led to successful production in this field also. Simultaneously with the experiments carried out at the Junghans works at Schorndorf, H. Krainer and B. Tarmann at Kapfenberg worked on the theory of extrusion casting and made a detailed report on it (Stahl und Eisen, 1949, p 13). I have taken a few theoretical data from this work. Table I /not included in original document/ shows the values of thermal conductivity λ, temperature conductivity α, density (specific gravity), specific heat C, melting point ϑ_S, the heat of fusion γQ_S and the heat content of steel, copper, aluminum, and brass.

A comparison with copper shows that the thermal conductivity of steel at 1,200° C is only about one-tenth, and the temperature conductivity only about one-fifteenth that of copper. The heat of fusion, per cubic centimeter, is approximately the same for steel and for copper. The great difference between the thermal and the temperature conductivities of steel and copper shows that the solidification processes of these two substances must take quite different courses. The heat emission from the extruded metal, in the case of steel, is definitely affected by the heat conductivity after solidification of the shell. This low heat and temperature conductivity makes casting by the extrusion process of very large cross sections extremely difficult, since the heat can be dissipated only in a radial direction. For that reason, slab ingots, sheet bars, billets, and tubes will be more suitable for extrusion casting than thick regular ingots.

In the experiments of Krainer and Termann, mostly 80- and 90-mm round billets were cast. At a pouring rate of 23 kg per min and a lowering speed of 0.6 m per min, 280 l of cooling water per minute were warmed from 10° C to 17° C. This corresponds to an emitted heat quantity of about 2,000 kg-cal per min, or 87 kg-cal per kg of steel poured. This latter quantity is low, and indicates that only relatively small amounts of heat have to be removed in the extrusion casting of steel. The casting temperature of the steel was 1,510° C. If the heat of fusion of the steel of 65 kg-cal per kg is considered, 20-25 kg-cal per kg remain for cooling the steel. Basing the calculation on a specific heat of steel of 0.6 - 0.18 kg-cal per kg and ° C, this corresponds to a cooling of about 125° C below the melting point. The quantity of heat removed is approximately the same for all types of steel. A calculation of the ingot mold will therefore have to be based on a heat of about 100 kg-cal per kg of steel, provided the molds are of similar size. The output in this case was (figure illegible) tons per hour. As the external surface of the mold was 0.08 sq m, the heat transfer on the mold wall is 1.5×10^6 kg-cal per sq m per hour. With the aid of the temperature curve, the heat transfer from water to mold wall is calculated as 22,000 kg-cal per sq m per hr per ° C. From the temperature curve on the outer wall of the mold the heat flow through the wall of the mold can be determined by means of this figure for heat transfer, and from that, in turn, the temperature of the interior of the wall of the mold can be computed.

The conditions which must be met in order to obtain the lowest possible temperature of the interior of the mold wall are thus established. The amount of cooling water, if taken as five to ten times the quantity of steel produced, is not of importance, because it warms up only moderately. However, the relative speed between cooling water and mold wall is of great importance; this must be taken into consideration also in blast furnace casting, where the flow of cooling water is often too low, so that steam bubbles form and the molds burn through. Figure [number of figure omitted - figure not included in original document] shows the effect of the rate of flow of the cooling water on the heat transfer. The curves are based on the formula by A. Schack: $\lambda = 2900 \times w^{0.85} (1 \quad 0.014\, t_{fl})$ [sic]. This figure clearly shows that rate of flow is the chief criterion. It also indicates that the effect of the water temperature is unimportant, because a small increase of the water temperature is compensated by the increase of the heat transfer which takes place as a consequence of the temperature increase. Water flow rates must be used which will yield heat transfer numbers of at least 20,000. Measures along that line must be taken in the construction of the mold, to ensure sufficiently high water flow rates.

Special attention must be paid to the manner in which these high rates are to be attained. An increase of the quantity of water flowing will, of course, increase the rate of flow, but it involves higher expenses. The use of turbulent flow is of advantage, but in this case, care must be taken to keep the pressure losses from becoming too high. The water conduits must be arranged in such a manner that a uniform cooling effect will be exerted over the entire surface of the mold. It is also necessary to use sufficiently pure water, so as not to interfere with the heat transfer. Formation of scale due to the use of water which had not been softened (water hardness 17°) has not been observed.

Figure [number not given - figure not included in original document] shows the effect of the mold material and the thickness of the mold wall on heat transfer. It shows that the effect of the wall thickness is of secondary importance

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in the case of copper, due to the high thermal conductivity. However, in the case of brass, and especially in the case of steel, the effect of the wall thickness is considerable. Unless the heat transfer is to be reduced too much, with the consequence of excessively high temperatures at the interior of the mold wall, the walls for brass and steel should not be more than about 3 mm thick. Since the interior of the mold has to have a very high-grade surface, brass is recommended as a particularly suitable material.

The heat transfer between mold wall and casting deserves particular attention. It could be computed easily from the pouring end of the mold, and was found to be 1,500 kg-cal per sq m per hr per $^{\circ}$ C. In comparison to the value given by W. Lueg, this seems quite low, but it becomes reasonable when it is considered that a very thin skin forms almost immediately. During further cooling of the casting, the heat transfer value at first remains constant, but after about half a minute it drops to less than 1,000 kg-cal per sq m per hr per $^{\circ}$ C. This drop is due to the fact that the steel decreases in volume because of the drop in temperature and a gap is formed between the steel and the mold wall. If an attempt is made to compute the heat transfer for this gap, it turns out to be a multiple of the heat transfer due to radiation. To this is added the thermal conductivity of the gas which fills the gap.

I should like to refer my readers to the mathematical treatment of the cooling and solidification phenomena of liquid metal, by Carl Schwarz of Duisburg-Hamborn, in Archiv fuer das Eisenhuettenwesen, 1931, p 177 ff. With the given gap widths, which amount only to a few tenths of a millimeter, the high heat transfer due to thermal conductivity can be explained only if it is assumed that about half of the gas which fills the gap consists of hydrogen. The presence of hydrogen seems entirely reasonable, since water vapor, at the high temperatures prevailing, will break down into hydrogen on the metal surface and will accumulate in the gap. On the basis of the data now available, Krainer and Tarmann were able to determine the solidification phenomena and the temperature distribution in the casting by means of the difference method.

Figure /number not given - figure not included in original document/ shows the curve of temperature on the surface of the casting. The great increase in temperature on the surface of the extruded metal after it has left the mold shows the great cooling effect inside the mold. The low surface temperatures when the extruded metal leaves the mold are due to the extremely poor thermal conductivity of the steel, and the calculation leads to the conclusion that the interior of the casting is still liquid at that moment. Figure /number not given - figure not included in original document/ shows the solidification within and outside the mold, and Figure /number not given - figure not included in original document/ shows the same conditions true to scale. Krainer and Tarmann carried out additional experiments, especially with molds 1000 to 1400 mm long, with a casting diameter of 80 mm, operating with casting rates of 1.2 to 2 m per min. It turned out that the optimal casting rate for molds of this size is about 1.5 m per min, corresponding to an output of about 60 kg per min of casting. At that casting rate, the surface of the casting seems to be improved, but only under certain conditions which still have to be definitely determined by experiment. The extrusion casting process is not as sensitive to maintaining theoretically exact pouring temperatures as the stationary casting process. The reason for this is that a change of the pouring temperature of 30° C means a change of the thermal content of the steel of about 5 kg-cal, which corresponds to about 5% of the quantity of heat to be removed in the mold. This fact is of great technological importance, since it is now possible to dispense with the furnace which keeps the molten steel at a constant temperature. As long as the installation is built in such a way, a 6-ton melt can be cast in about 20 minutes and a 10-ton melt in about 30 minutes.

The installation at the Junghans plant at Schorndorf can cast 6 tons per hour, using slab cross sections of about 100 sq /unit of measure not given/ and could increase this output if the cross section were increased. Junghans has

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even succeeded in producing 300-mm rounds and slabs. During the inspection of his installation at Schorndorf, carried out by Dr Baake of Vesta and myself, Junghans told us that according to his experiences, up to the present, steel casting was easier than casting copper, brass, zinc, or light metal. According to him, the main difficulty in steel lies in the difficulty of pouring a constant amount of steel per unit of time into the mold at the high temperatures of molten steel. However, he stated that he had already solved that problem, too. The billets made in his plant by the extrusion casting process were rolled at the Nuremberg ironworks. Dr Stich, chief of the rolling department of that plant, who used to be an employee of mine and who is a very reliable and objective expert, confirmed that these billets are easier to roll than the bloomed ingots he receives from the Gute-Hoffnungs-Huette. Billets which we inspected made by the extrusion casting process did show a scaled surface; however, in my opinion, spraying with powerful streams of water immediately after the casting has left the mold, would do away with this and prevent rescaling.

In contrast to the arrangement used by Krainer and Tarmann, Junghans uses short molds, about 300 mm high, moving them steadily downward for about 20 to 30 mm, so that the steel does not carry out any motion relative to the mold during its solidification. After the motion of 20 to 30 mm, the molds are rapidly moved back up. This motion constantly destroys the gas layer which forms between the metal and the mold. This layer has an insulating effect which prevents the desired quick solidification. Junghans makes the molten steel by preblowing of cupola-furnace pig iron in a Bessemer converter. In all his experiments, he has thereby obtained a silicon content of at least 0.07 to 0.15% and sometimes higher. The steel is thus semikilled. It remains to be seen whether the good results obtained up to now can also be obtained in the casting of rimmed Thomas of open-hearth steel, since in that case, the solidification process is accompanied by a gas formation which did not occur in Junghans' experiments. However, it can be stated that electric-arc or open-hearth steels with higher carbon or alloy content can be cast by the extrusion process without difficulty. The cross sections of the cast billets were all uniform and showed practically no difference in chemical composition at the edge and at the center. This seems entirely reasonable, since in Junghans' experience, thin cross sections are more uniform and have less segregation than when made by the stationary casting method.

The experiences gained in the Junghans process therefore allow us to conclude that this process permits the production of billets and slabs, and of tube cross sections for piercing made of killed steels, with uniform composition over the entire cross section, which can be placed on finishing-mill trains without having to be bloomed, and with the saving of the considerable cost due to the necessity in the customary process of cutting off the ends of the ingots. This process will effect a saving, especially in the production of high-grade steel. In this case, it should be pointed out that the extrusion casting method, contrary to the customary bottom plate casting method, will eliminate the possibility of impurities in the form of parts or spout and runner stones getting into the cast. To achieve the output which is required in steel production, it will be necessary to cast several extrusions simultaneously. This will hardly mean a considerable increase in expense, as the costs even of a multiple extrusion casting installation will be only a fraction of the cost of a heavy blooming-mill train.

Both from a metallurgical and from a technological point of view, the Junghans extrusion casting process can today be considered as ready for large-scale application. Operating with large quantities will still cause difficulties, especially the uniform setting of the pouring rate if several extrusions are being cast simultaneously. This is still a problem for the designers and especially [redacted] 50X1-HUM

for the electrical engineers. However, the problem does not seem to be soluble and will probably be solved in a shorter time than it took to attain the present-day state of development in metallurgical technology.

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